eRHIC SRF Cavity R&D

- 422 MHz SRF linac cavity
- HOM damping for the 422 MHz cavity

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BROOKHAVEN NATIONAL LABORATORY
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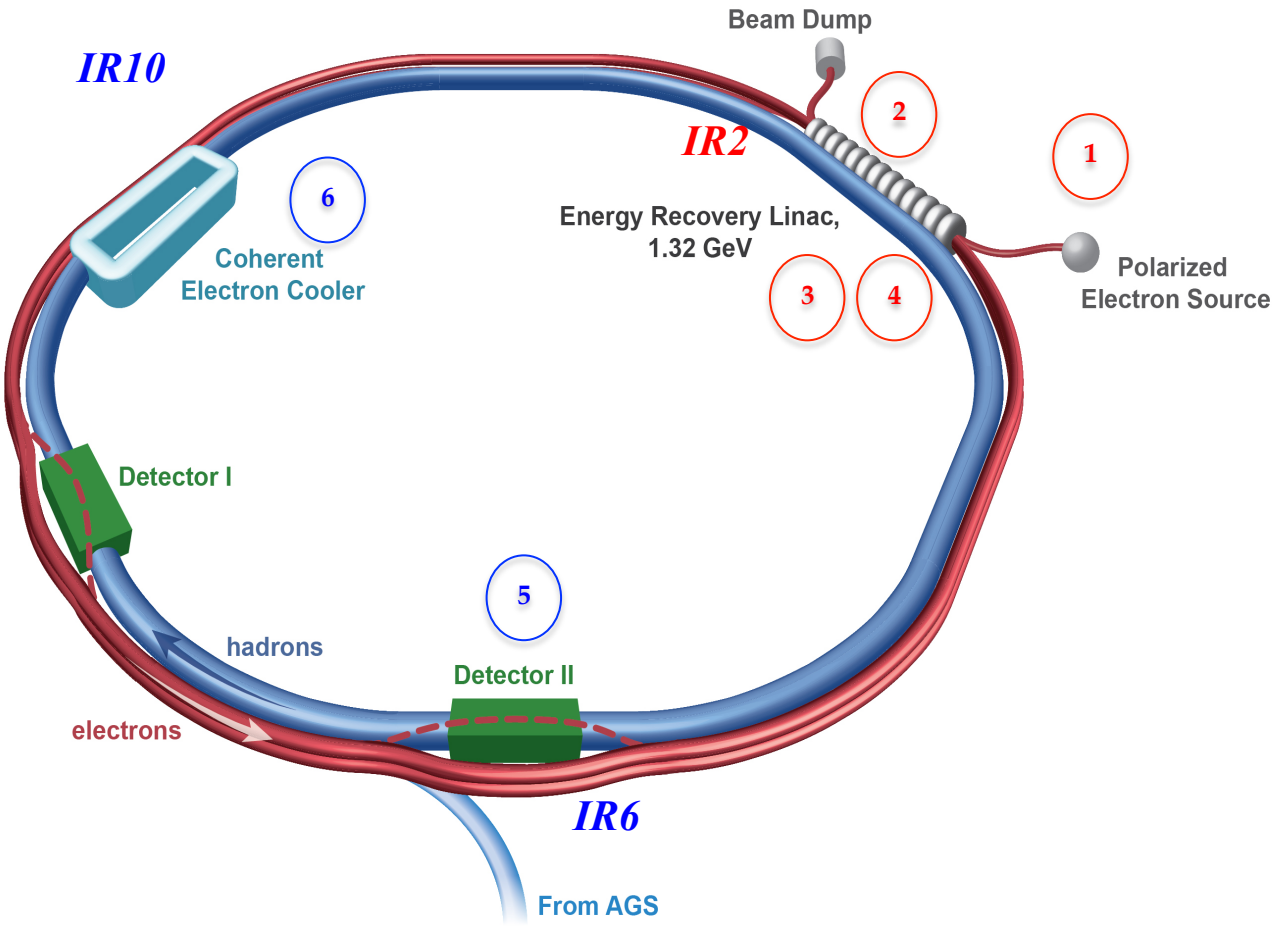
Office of Science
U.S. DEPARTMENT OF ENERGY

Outline

- Technical Overview and Project Status
- R&D Project Description and Scope (3 years)
- Deliverables and Key Performance Parameters
- Major Milestones (3 years)
- Risk and Contingency
- Summary

Technical Overview: identify R&D challenge



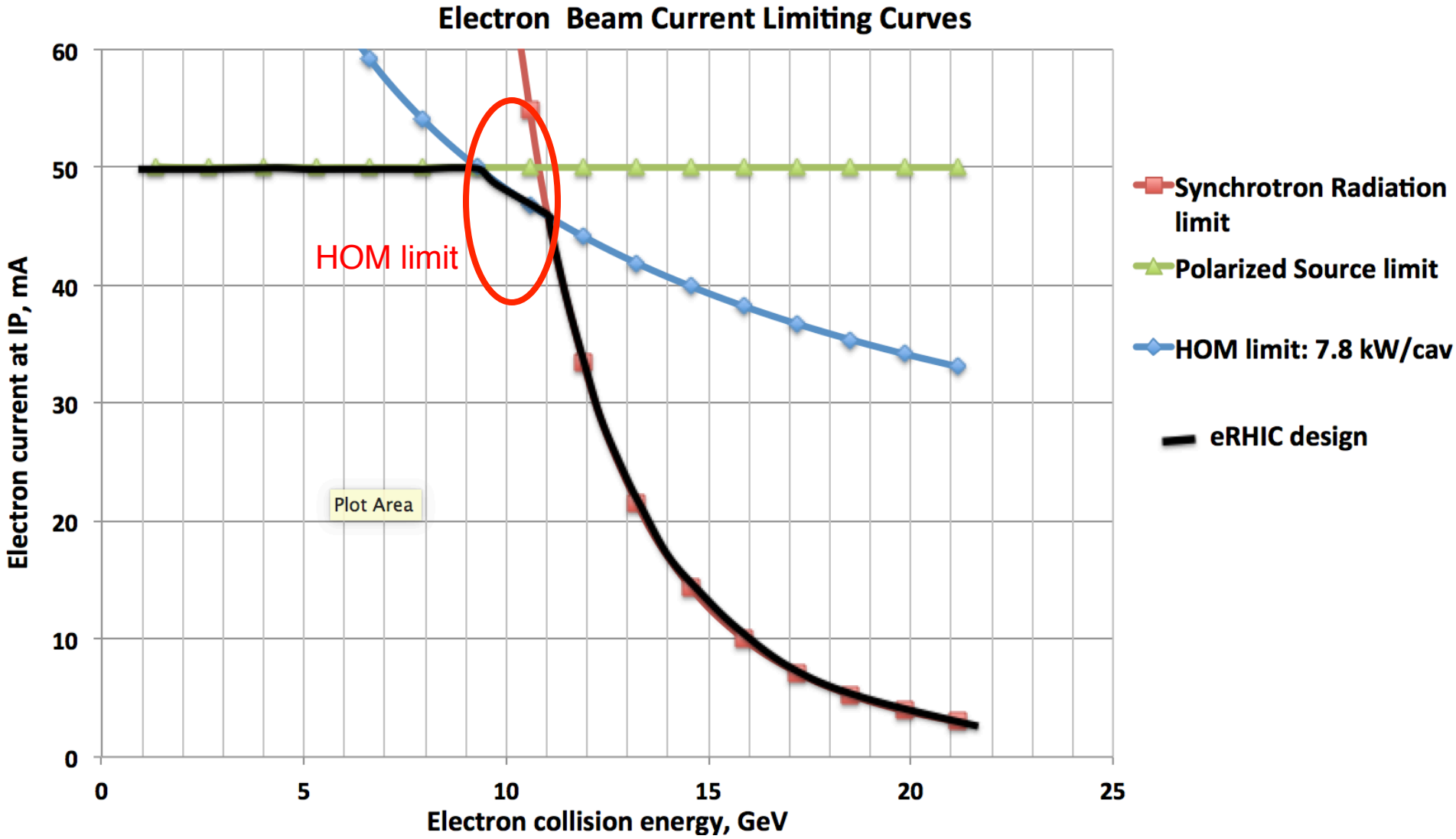
- Major SRF Challenges for R&D
  - 5-cell 422 MHz SRF cavity for main linac
  - HOM damping for the 422 MHz cavity

Why 422 MHz cavity and its challenge?

- **Why 422 MHz cavity?**
  - FFAG lattice eRHIC design has up to 16 turns ERL in the main linac, which generates a big amount of HOM power in the 704 MHz cavity (previous design for conventional lattice eRHIC), so we have to choose a lower frequency SRF linac;
  - Compared with the previous conventional lattice eRHIC design using a 704 MHz SRF linac, there are other benefits for using a 422 MHz SRF linac:
    - » (1) higher Beam-Break-Up (BBU) threshold current,
    - » (2) longer bunch length,
    - » (3) lower energy spread,
    - » (4) higher beam polarization,
    - » (5) easier path length control,
    - » (6) higher cavity quality factor,
    - » (7) higher RF power efficiency,
    - » (8) lower transient, and
    - » (9) lower total HOM power

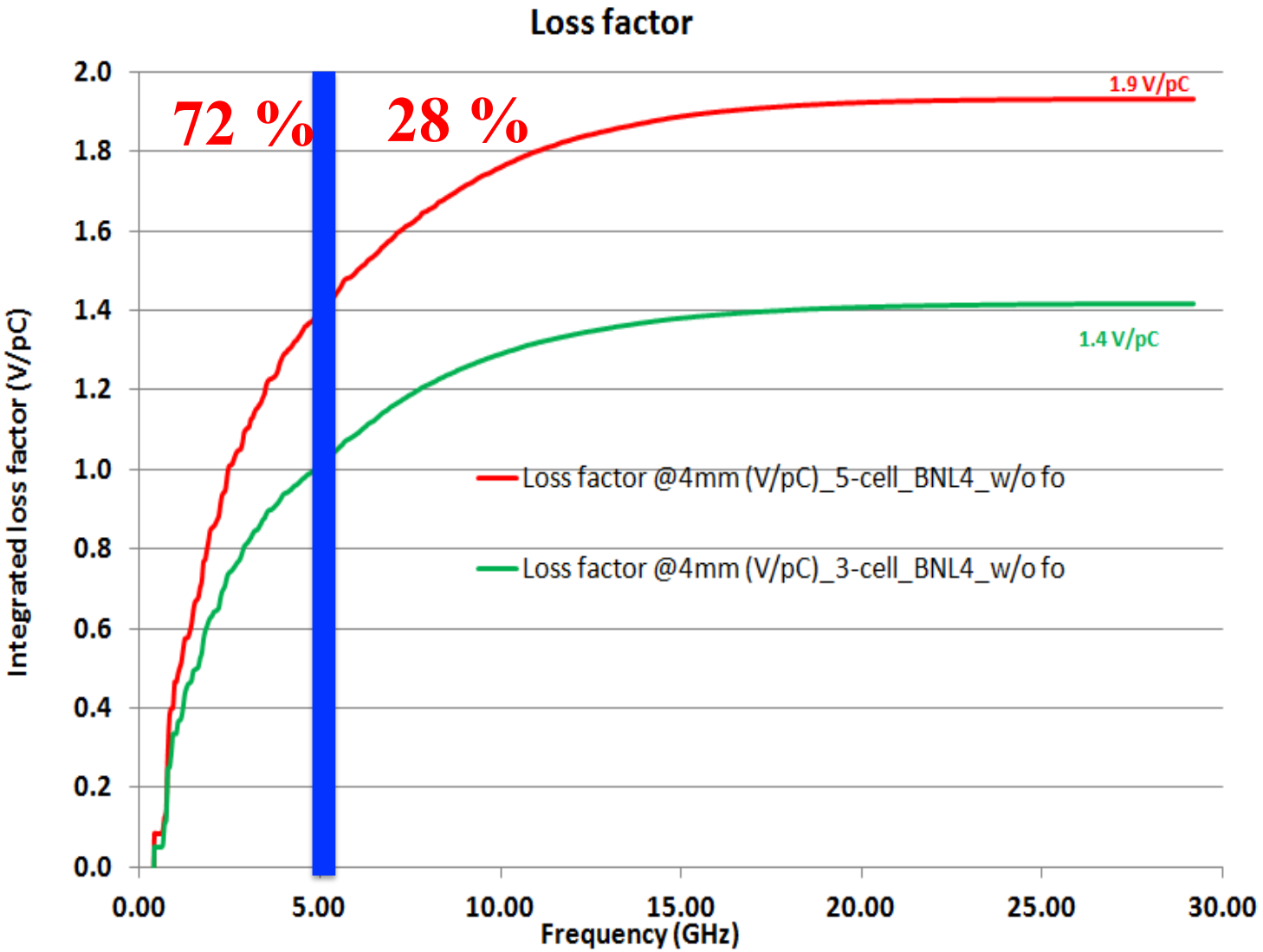
- **Why 5-cell 422 MHz cavity is a challenge?**
  - Largest multi-cell cavity (2.65 m long).
  - Rare fabricating/processing facilities large enough in industry or labs.
  - No experience in handling such large cavities.

HOM damping requirement



- eRHIC in intermediate energy, 5.3 nC, 50 mA, 7-Pass ERL.
- Luminosity is limited by capability of HOM damping (7.8 kW per cavity).

HOM Spectrum



- Electron beam bunch length: RMS 4 mm
- Frequency range: 0.5 to 30 GHz

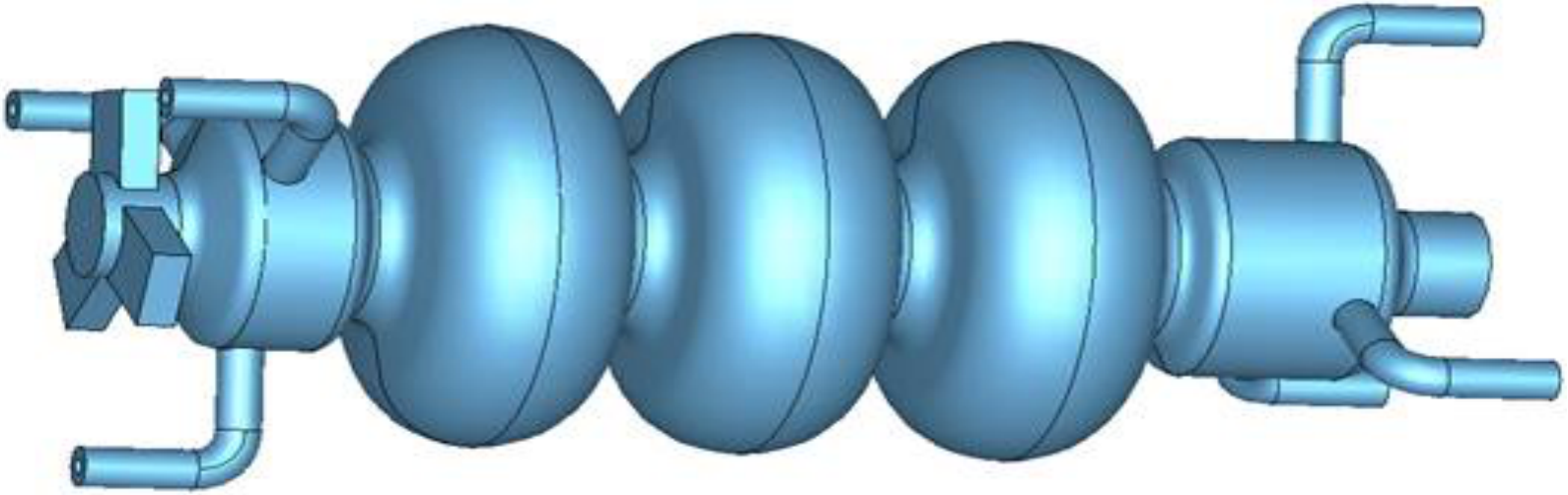
HOM damping challenge and scheme

- **HOM damping: to increase BBU threshold (dipole) and reduce cryogenic load (monopole) => high eRHIC luminosity;**

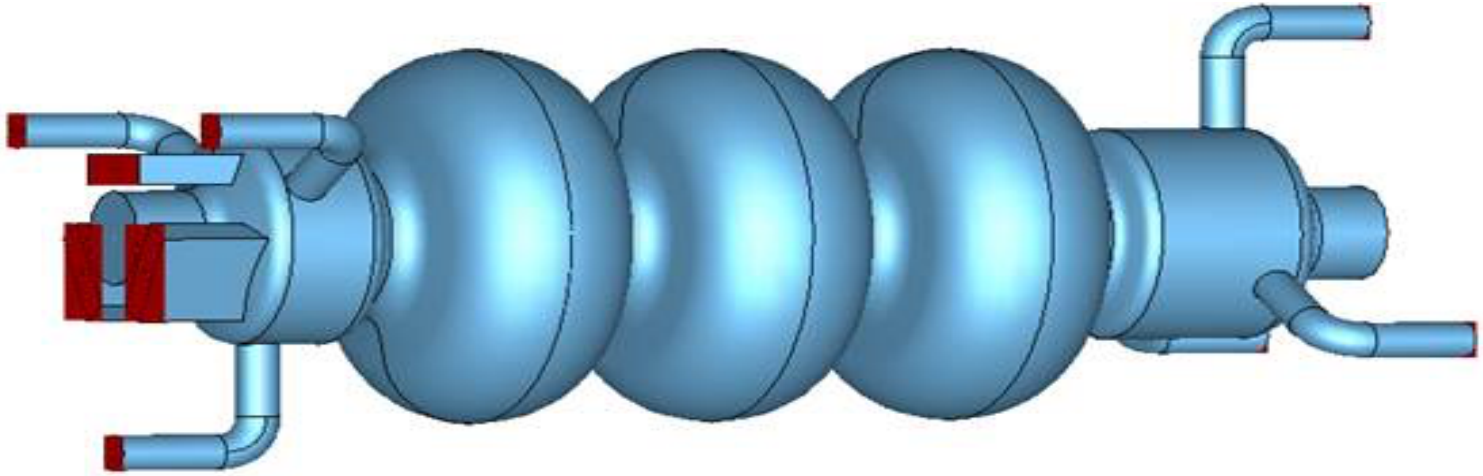
- **Challenges for HOM damping**
  - **High power: 7.8 kW per cavity;**
  - **Full spectrum: 0.5 GHz to 30 GHz;**
  - **Compact design to fit the linac into the existing RHIC tunnel.**

- **HOM damping scheme**
  - **Baseline: Coaxial-line couples for low frequency HOMs plus waveguide couplers for high frequency HOMs;**
  - **Backup: Coaxial-line HOM couplers plus beam-pipe HOM absorber**

HOM damping scheme (1): Coaxial-line Plus Waveguide

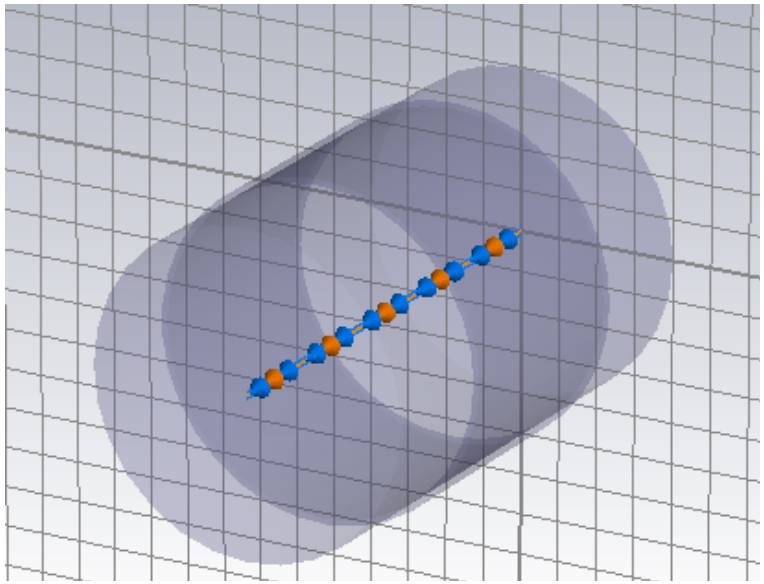


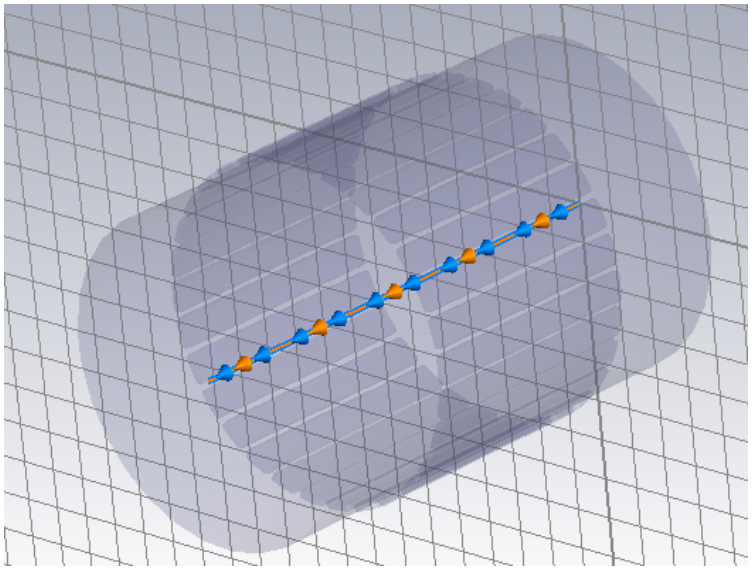
Scheme 1 (a): waveguide on the beam tube

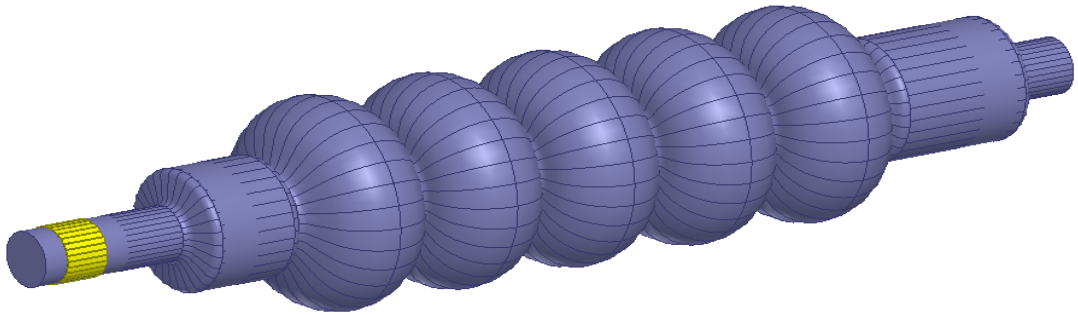


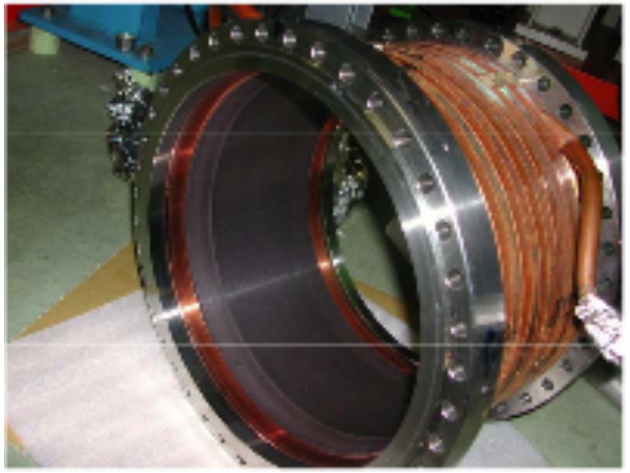
Scheme 2 (a): waveguide on the taper

HOM damping scheme (2): Coaxial-line plus beam pipe absorber









- Three coaxial HOM couplers at each side of the cavity (not in the model);
- Room temperature beam pipe HOM damper.

- HOM power in Super KEKB reached 16 kW in operation.

R&D Project Description and scope

- **422 MHz cavity**
  - There is very little experience on fabricating and processing such big size and weight cavity over the world;
  - The main R&D efforts includes cavity fabrication for its size/weight and post-processing for high performance.

- **HOM couplers for 422 MHz cavity**
  - This R&D project is aimed to develop and optimize a high-power, full-spectrum HOM damping scheme;
  - The conceptual design for such a damping system consists of six coaxial-line HOM couplers and three waveguide HOM couplers;
  - The couplers and their RF windows will be designed, prototyped and tested first as a package with a 5-cell copper cavity for full spectrum HOM damping study;
  - Then, the HOM damping scheme will be verified on a 3-cell 422 MHz Nb cavity at 2 K to finalize the design.

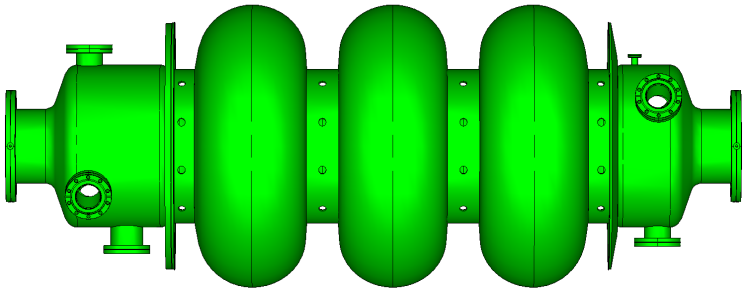
R&D Project Schedule

- **422 MHz cavity: 3 years.**
  - 2014 to April 2015: Physics design of a full scale 5-cell eRHIC cavity;
  - April 2015 to Sept. 2016: Engineering design and fabrication of the prototype cavity;
  - Oct 2016 to Sept. 2017: Performance study through vertical tests.

- **HOM couplers for 422 MHz cavity : 3 years.**
  - Oct 2015 to Sep 2016: Full-scale 5-cell copper cavity fabrication; RF design of HOM couplers and prototype measurements; RF design and thermal analysis of RF windows.
  - Oct 2016 to Jun 2017: Prototype of RF windows; Engineering design of Nb coaxial line HOM coupler and beam-pipe damper (waveguide).
  - Jul 2017 to Sep 2018: HOM damping tests with Nb cavity in vertical test facility and finalization of the HOM damping scheme.

Current Project Status

- **422 MHz cavity**:
  - 5-cell 422 MHz cavity design is complete
  - Mechanical Stress analysis of both 5-cell 422 MHz cavity and 3-cell 422 MHz cavity is complete
  - The contract was awarded to RI in Germany



- **HOM couplers for 422 MHz cavity**
  - RF simulations are in progress

Deliverables and Key Performance Parameters (KPPs)

- **422 MHz cavity**:
  - RF and engineering design of 5-cell cavity;
  - 3-cell 422 MHz niobium cavity;
  - Fabrication and cavity treatment procedures for multi-cell (3 or 5-cell) 422 MHz cavities;
  - Demonstrate the 3-cell 422 MHz cavity performance: a quality factor $Q_0 > 5\times10^{10}$ at $E_{acc} = 18.5$ MV/m.

- **HOM damping for 422 MHz cavity**
  - 5-cell 422 copper cavity and its full HOM spectrum study;
  - Design, prototypes and tests of two HOM damping schemes: coaxial-line HOM couplers plus waveguide HOM couplers and coaxial-line HOM couplers plus beampipe absorber;
  - Fabricate and test actual HOM couplers and RF windows on the 3-cell 422 MHz Nb cavity at 2 K to verify their RF and thermal performance, including

    (1) Demonstrate the HOMs' external Q of less than 50,000 at low frequency HOMs;

    (2) S21 parameter measurement for the high frequency HOMs;

    (3) High power test for the RF windows at low temperature.

Major Milestones

#	Milestone	Date
1.1	422 MHz cavity is delivered from vendor to BNL	09/2016
1.2	422 MHz cavity vertical testing at BNL is complete	09/2017
2.1	Completion of the HOM spectrum study on Cu cavity	09/2016
2.2	Prototype tests on Cu cavity show the HOM damping scheme's HOM damping capability in terms of external Q up to 30 GHz	12/2016
2.3	Completion of the actual HOM couplers and their window design and fabrication	09/2017
2.4	Vertical tests of the HOM damping scheme on the 3-cell 422 MHz cavity at 2 K is complete	09/2018

Risks and Contingency

- **422 MHz cavity**
  - The cavity may not be fabricated and processed properly due to lack of experience on such a big size/weight cavity;
  - The cavity may not reach the performance: $Q_0 > 5\times10^{10}$ at $E_{acc} = 18.5$ MV/m;
  - Decision point: Cavity's performance test results in Sept. 2017

  If the performance is not reached, N-doping will be required (we are working on N-doping with a single cell 400 MHz cavity borrowed from Jlab).

- **HOM couplers for 422 MHz cavity**
  - The proposed HOM scheme may not be able to couple up to 7.8 kW per cavity.
  - The residual HOM *Q*'s may be still too high.
  - Decision point: Sept. 2018

  If coaxial-line plus waveguide HOM damping scheme doesn't work, we will have to use beampipe HOM damper (effort has been made on this study).

Summary

- 5-cell 422 MHz cavity is one of challenges in the eRHIC SRF system due to limited experience on handling such a big size and heavy weight cavity and its required high performance for eRHIC;
- A prototyping eRHIC cavity with 3-cell cavity has been carried out and on schedule;
- Well-damped HOM damping scheme for 422 MHz cavity linac is critical to reach full eRHIC luminosity;
- R&D on HOM damping has been started with RF simulations, prototypes have to be fabricated and tested.